Chapter

17 ELECTRONICS

⇒ There are some materials having properties intermediate between conductors and insulators, they are classified into a specific group called 'Semiconductors'.

⇒ They are not good conductors but not good insulators.

⇒ Example includes, Germanium and silicon.

⇒ These substances have crystalline structure.

⇒ They are formed by covalent bonds.

⇒ But the important property of semiconductors is when we add some impurity to it, their conductivity can be increase or decrease by adding these impurities, depends upon conditions.

⇒ So, we can control flow of charges by this way, which is actually 'ELECTRONICS'.

⇒ Now we are going to understand some conceptual points about semiconductors.

Semiconductors

✓ Those solids which possesses conductivity and resistivity between conductors and insulators.

✓ The gap between valence and conduction band is small.

✓ Have few free electrons at room temperature (Behave as insulators), because at low temperature the valence band is completely full and conduction band is completely empty.

✓ Formed by covalent bonds.

✓ Have negative temperature coefficient of resistance. $R_{semiconductor} \propto \frac{1}{T}$.

✓ Conductivity: 10^{-5} *to* 10^{0} Sm^{-1}.

✓ Resistivity: In between 10^{-4} *to* 0.4 Ωm.

✓ Elemental semiconductors: semiconductor consists of single elements. (Example *Ge and silicon*)

✓ Compound semiconductors: consists of two or more elements.

Organic: Anthracene etc.

Inorganic: Calcium sulphate, Gallium arsenide etc.

General Discussion

1) Effect of Temperature on Semiconductors:

The conductivity of semiconductors changes with temperature.

⇒ At absolute zero temperature:

✓ All electrons are tightly held.

✓ The covalent bonds are very strong.

✓ No free electrons exist.

✓ Valence band is full and the gap between valence band and conduction band (forbidden gap) is large.

✓ Semiconductor at this temperature behave as insulator.

⇒ Above absolute zero temperature (4K):

✓ By increasing temperature some covalent bonds broken and now the free electron is allowed to move.

✓ These free electrons can constitute to an electric current now.

✓ Note that resistance of semiconductor varies inversely with temperature, so resistance decreases.

✓ Note that unlike other temperature at room temperature current through a pure semiconductor is too small to be any of practical value.

2) Formation of Hole in semiconductors:

As the temperature of semiconductor some of the electrons acquire sufficient energy to enter into a conduction band and thus become free electrons.

Note that each time the free electrons move into conduction band a hole is created in conduction band.

3) Current in semiconductor:

Note that current in semiconductor is due to both free electrons and holes.

Current in semiconductor $= I_{electron} + I_{hole}$

4) Description of Hole:

- ✓ Removal of one electron from valence band produce a single hole in valence band.
- ✓ Note that thermal energy (Temperature) creates hole electron pairs.
- ✓ It is sometime called missing electron.
- ✓ Hole has positive charge.
- ✓ A hole is considered as a seat of positive charge, having magnitude of charge equal to that of an electron.
- ✓ Note that the movement of Hole (production/Contribution to electric current) is due to movement of free electrons from valence band to conduction band.
- ✓ Effective mass of hole is more than electron.
- ✓ Mobility of hole is less than electron. Or The drift velocity of electrons (v_e) is greater than that of holes (v_h).
- ✓ Note that, Holes acts as virtual charge, although there is no physical charge on it.

5) Doping:

The process of adding impurity to semiconductor is called Doping.
We know that intrinsic semiconductor has little conduction capability at room temperature to make its conductivity of our own choice we add some impurities to that intrinsic or pure semiconductors.

6) Dopants:

The atoms or molecules that is added to intrinsic semiconductors to make its conductivity better.

- ✓ The conductivity of semiconductor having dopants has greater conductivity than unlike intrinsic conductor (at room temperature) but its conductivity is less than that of conductor like copper.
- ✓ Note that the concentration of impurities or dopants should be in proper amount. For about 10^8 atoms of semiconductor 1 atom of impurity should be added.
- ✓ The size of the dopant`s atoms should be same to that of the semiconductor atoms.
- ✓ Make sure that the presence of dopants atom does not disturb the crystal lattice of semiconductor.

7) Doped semiconductor:

The semiconductor to which the dopants are added is called Doped semiconductor.

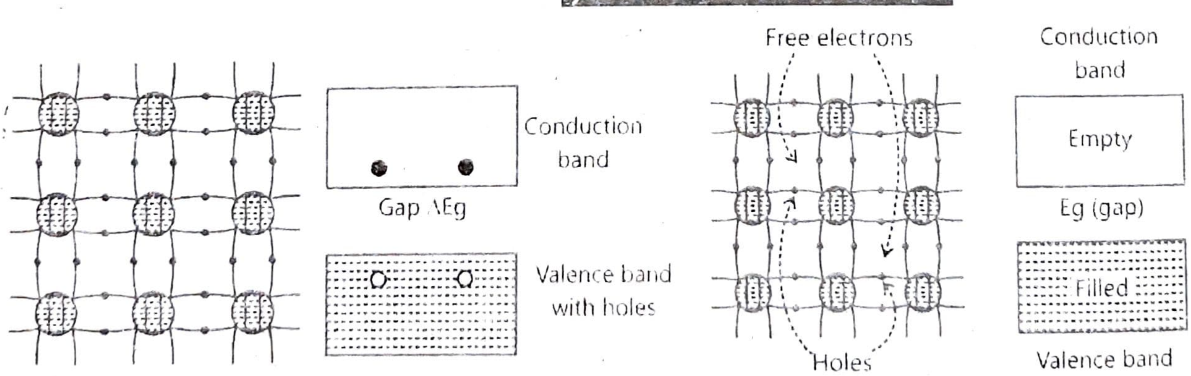
8) Types of Dopants:

- ✓ There are two types of dopants.
  - ➢ Pentavalent atoms: these types of dopants have 5 valence electrons. (E.g. Arsenic, Antimony)
  - ➢ Trivalent atoms: these types of dopants have 3 valence electrons. (E.g. Boron, Aluminum)

Types of Semiconductors

1) Intrinsic semiconductors
2) Extrinsic semiconductors

1) Intrinsic semiconductors:



⇒ A pure semiconductor having no impurity added is called intrinsic semiconductors.
⇒ In an intrinsic semiconductor the number of free electrons is equal to number of holes.
⇒ In intrinsic semiconductor even at room temperature the hole electron pair is created.
⇒ It has no practical use because of low conductivity.
⇒ Note that the current inside intrinsic semiconductor is due to free electrons and holes;

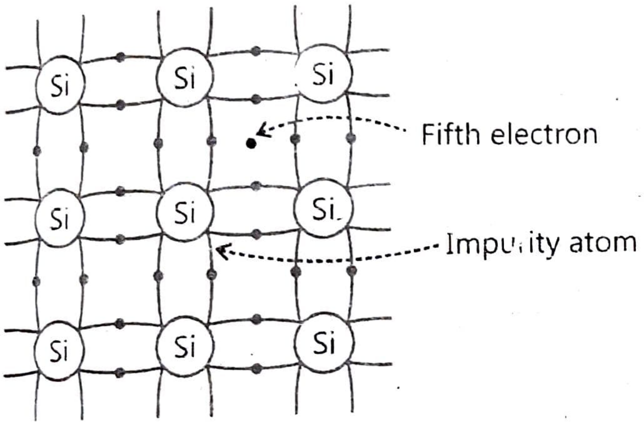
$$I_{Intrinsic\ Semiconductor} = I_{electron} + I_{Hole}$$

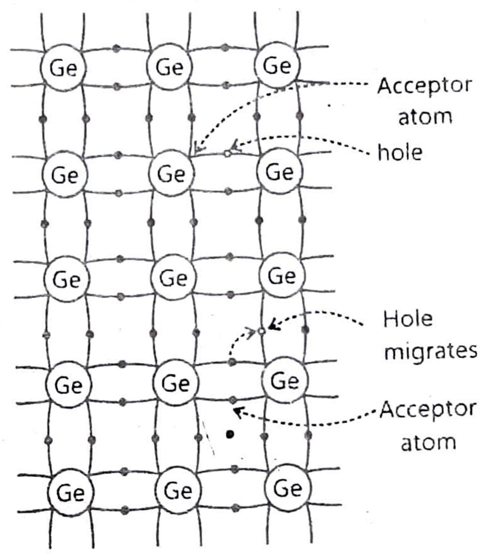
⇒ There are more semiconductors available but few have greater application and according to course criteria we have pick only two of them.
1: Silicon
2: Germanium

⇒ Both Si and Ge are tetravalent. (Have four electrons in their valence shell).
⇒ Their different atoms are held together through covalent bonds.
⇒ There are no practically free electrons in an intrinsic or pure crystal of Germanium and Silicon.
⇒ Now we are going to explain it separately;

Silicon	Germanium
Tetravalent (Have four valence electrons)	Tetravalent (Have four valence electrons)
Can form four covalent bonds, because it can share it's all four electrons with its neighbors and form four covalent bonds.	Can form four covalent bonds, because it can share it's all four electrons with its neighbors and form four covalent bonds.
Have no free electrons at room temperature...	Have no free electrons at room temperature...
The forbidden energy gap is 0.7 eV.	The forbidden energy gap is 1.1 eV.

2) Extrinsic semiconductors:





⇒ An impure semiconductor is called extrinsic semiconductor.

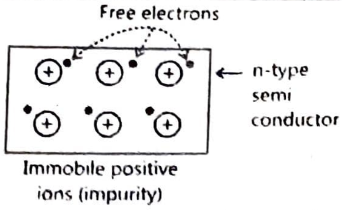
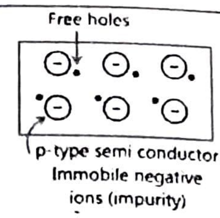
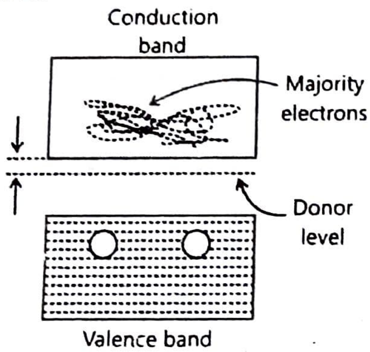
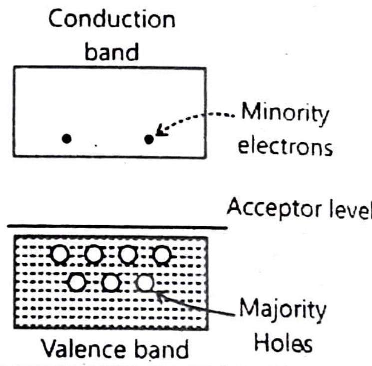
Intrinsic Semiconductor + Impurity = Extrinsic semiconductor

⇒ It is used in electronic devices, because of high conductivity.
⇒ Extrinsic semiconductors are made to increase the numbers of holes and electrons (Charge carriers).
⇒ If pentavalent impurity is added to intrinsic semiconductor a large number of free electrons are produced.
⇒ If trivalent impurity is added a large number of holes are produced in semiconductor.
⇒ Based on impurity added there are two types of Extrinsic/Doped semiconductor.

Types of Extrinsic Semiconductor on the basis of Impurity added

1) n-Type semiconductors
2) P-Type semiconductors

n-Type Semiconductor	P-Type semiconductor
1) Controlled amount of suitable pentavalent impurities is added. Example: Arsenic, Antimony etc.	1) Controlled amount of suitable trivalent impurities is added. Example: Gallium, Indium etc.

 The impurity atom on donating electrons becomes positive ions. However, the overall charge on the semiconductor is zero.	 The overall charge on p-type semiconductor is zero. The positive charge of free holes is balanced by the negative charge of immobile impurity ions.
2) Impurities which produce n-Type semiconductor are called Donor impurities.	2) Impurities which produce p-Type semiconductor are called Acceptor impurities.
3) Have large number of free electrons.	3) Have large numbers of Holes...
4) Thermal energy of room temperature still generates a few hole-electron pairs. However, the number of electrons provided by the pentavalent impurity far exceeds the number of holes. It is due to this predominance of electrons over holes that is called n-Type, n stands for negative. 	4) Thermal energy of room temperature still generates a few hole-electron pairs. However, the number of holes provided by the trivalent impurity far exceeds the number of free electrons. It is due to this predominance of Holes over electrons that is called P-Type. P stands for Positive. 
5) $n_e\, n_h = n_i^2$ $n_e \rightarrow$ number density of electron in conduction band $n_h \rightarrow$ number density of holes in the valence band $n_i \rightarrow$ number density of intrinsic carrier (Holes and free electrons)	5) $n_e\, n_h = n_i^2$ $n_e \rightarrow$ number density of electron in conduction band $n_h \rightarrow$ number density of holes in the valence band $n_i \rightarrow$ number density of intrinsic carrier (Holes and free electrons)
6) $n_{electron} \cong N_d \gg n_h$ $N_d \rightarrow$ Number of donor atoms	6) $n_{Hole} \cong N_a \gg n_{electron}$ $N_A \rightarrow$ Number of Acceptor atoms
7) The conduction of current is mainly due to electrons.	7) The conduction of current is mainly due to Holes (Positive charges).
8) When potential difference is applied the free electrons in the crystals will be directed toward the positive terminal constituting electric current.	8) When potential difference is applied the holes in the crystals are shifted from one covalent bond to another, As the holes are positive charged therefore, they are directed toward the negative terminal constituting Hole current.
9) The donor energy level is just below the bottom of the conduction band.	9) The acceptor energy level is just below the top of valence band.

PN Junction

⇒ A semiconductor crystal having one half made up of P-Type and other half is made of n-Type and the contact surface dividing the two halves is called PN Junction.

⇒ It is also called Semiconductor diode/crystal diode or Junction diode.

⇒ ***Depletion Region:***

✓ As soon as PN junction is formed electrons from N-Type material diffuse into P-Type and fill some of the holes there and holes from P-Type diffuse into N-Type and are filled by electrons.

The migration of electrons and holes results in n-section acquiring a positive charge and P-section acquires a negative charge.

- ✓ These two layers (Positive and negative charges) form a region called Depletion layer or depletion region.
- ✓ Why this region is called Depletion Region?

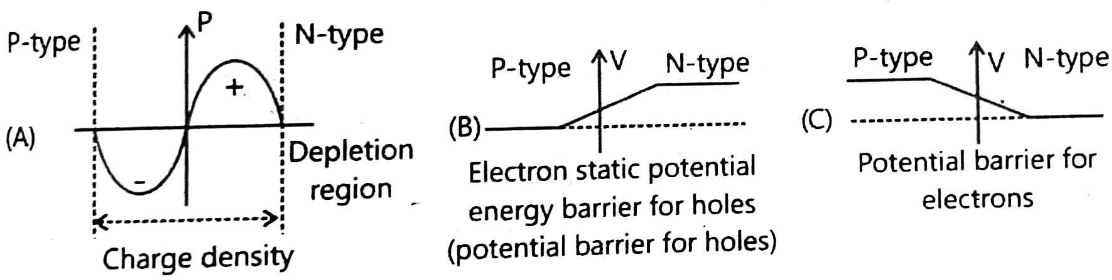
Within a very short period of time the steady state condition is reached and further movement of charge carriers across the junction stops. It is because the electric field set up by the depletion layer acts as a barrier to further diffusion of electrons into P-Region and holes into N-Region. It is so called because the free electrons and holes have been depleted (Emptied).

- ✓ The thickness of depletion layer is 1 micron = 10^{-6} m.
- ✓ $Width\ of\ Depletion\ region \propto \frac{1}{Doping}$
- ✓ $Depletion \propto Temperature$
- ✓ The P-N junction diode is equivalent to capacitor in which the depletion layer acts as a dielectric.

⇒ Potential barrier:

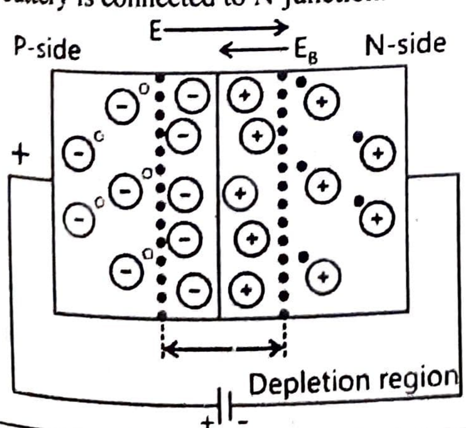
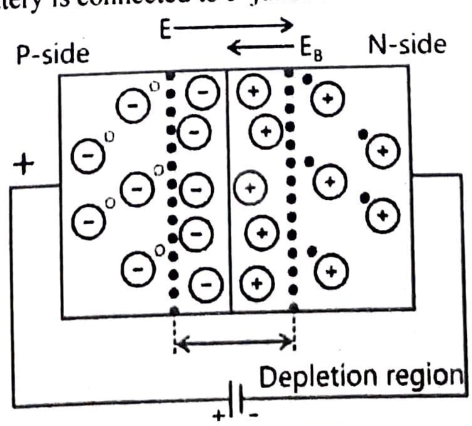
- ✓ After the formation of depletion region further movements of the charge carriers stops, there exists a potential difference across the depletion layer which is called barrier potential.
- ✓ Represented by V_B.
- ✓ For $Silicon, V_B = 0.7\ V$ and $For\ Germenium\ Ge = 0.3V$
- ✓ On the average the potential barrier in P-N junction is ~ 0.5 V and the width of depletion region ~ 10^{-6}m.

⇒ For holes the potential on the N-sides is higher. Holes cannot cross the depletion region because of this barrier potential. Figure (B). For electrons the potential barrier is shown in Figure (C);



⇒ Biasing of PN Junction:

- ✓ The term Bias refers to use of DC voltage to establish certain operating conditions for an electronic device.
- ✓ In case of PN junction two kinds of Biasing are possible.
  1) Forward Biasing
  2) Reverse Biasing

Forward Biasing	Reverse Biasing
1) Positive terminal of the battery is connected to the P-junction and negative terminal of the battery is connected to N-junction. 	1) Positive terminal of the battery is connected to the N-junction and negative terminal of the battery is connected to P-junction. 
2) In this case PN-Junction diode acts as a closed	2) In this case PN-junction behave as an open

switch.	switch (no current flows).
3) Width of depletion region decreases.	3) Width of depletion region increases.
4) In forward biasing resistance offered $R_{Forward}$ = $10\Omega - 15\Omega$.	4) In reverse biasing resistance offered $R_{Reverse}$ = $10^5\Omega$.
5) The electric field at the barrier, due to the Battery is from P side to N side (forward bias). This is an opposition to the barrier electric field.	5) Reverse bias supports the potential barrier and no current flows across the junction due to the diffusion of the majority carriers.
6) ***Cut-in (Knee) voltage:*** The voltage at which the current starts to increase rapidly. For Ge it is 0.3 V and for Si it is 0.7 V	6) ***Break down voltage:*** Reverse voltage at which break down of semiconductor occurs. For Ge it is 25 V and for Si it is 35 V

⇒ ***Problems associated with Reverse Biasing if it is too high (Reverse Breakdown):***

If the reverse biased voltage is too high, then breakdown of P-N junction diode occurs. It is of following two types;

Zener effect or breakdown	*Avalanche effect or breakdown*
When reverse bias is increased the electric field across the junction also increases. At some stage the electric field becomes so high that it breaks the covalent bonds creating electron, hole pairs. Thus, a large number of carriers are generated. This causes a large current to flow. This mechanism is known as Zener breakdown. $B_{Breaking} \geq 0.5$	At high reverse voltage, due to high electric field, the minority charge carriers, while crossing the junction acquires very high velocities. These by collision breaks down the covalent bonds, generating more carriers. A chain reaction is established, giving rise to high current. This mechanism is called avalanche breakdown. $V_B < 0.5$

Rectification

⇒ The conversion of AC into DC is called Rectification.

⇒ A device used for Rectification purpose is called Rectifier.

⇒ It is also sometime called Linearization which mean to improve something.

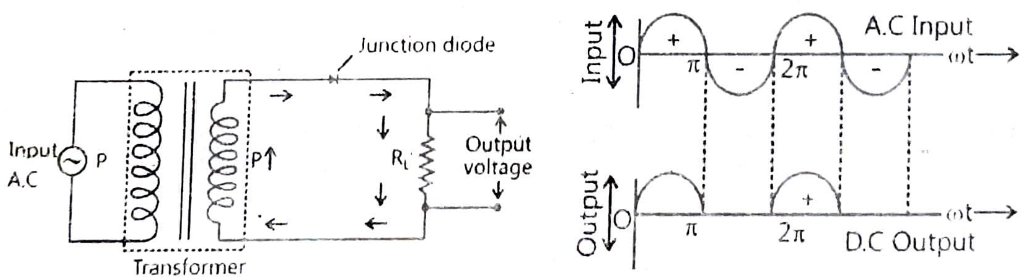
⇒ **Principle:**

This rectification is based on switching action of PN-Junction (For forward bias PN-Junction acts as a closed switch, and in case of Reverse bias it acts as an open switch)

⇒ There are two types of Rectifiers;

1) Half wave rectifier
2) Full wave rectifier

1) Half wave rectifier:



✓ When the P-N junction diode rectifies half of the ac wave, it is called half wave rectifier.

✓ During positive half cycle

Diode ⟶ forward biased

Output signal ⟶ obtained

✓ During negative half cycle

Diode ⟶ reversed biased

Output signal ⟶ not obtained

✓ Output voltage is obtained across the load resistance R_L. It is not constant but pulsating (mixture of ac and dc) in nature.

✓ $I_{ac} > I_{dc}$

✓ In this case frequency of DC is equal to Frequency of AC.

✓ ***Expression for output DC. voltage:***

$$Output\ d.c.\ voltage = Mean\ load\ current \times load\ resistance\ i.e.\ V_{dc} = I_{dc} \times R_{Load}$$

$$But\ I_{dc} = \frac{I_o}{\pi}$$

where I_o is the maximum value of the secondary half wave current

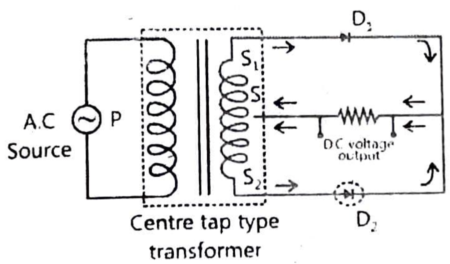
$$V_{dc} = \frac{I_o}{\pi} \times R_{Load}$$

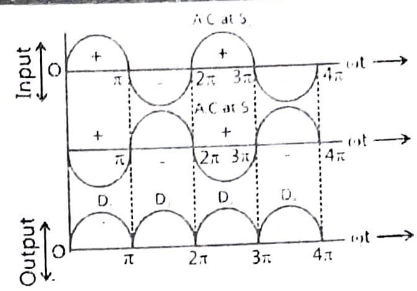
$$E_{ac} = E_{DC} = \frac{V_o}{\pi}$$

✓ **Disadvantages:** Since the output signal is discontinuous, so the efficiency of half wave rectifier is small.

The output is not pure DC but it is a fluctuating (or pulsating AC.) which contains AC. components or ripples also.

2) Full wave rectifier:





✓ It rectifies both cycle of ac input signal.

✓ It consists of two diodes D_1 and D_2 . They conduct alternately during positive and negative half cycle of input ac and a unidirectional (or dc) current flows in output.

✓ During positive half cycle:

Diode: D_1 ——————▶ forward biased

Diode: D_2 ——————▶ reverse biased

Output signal ——————▶ obtained due to D_1 only

✓ **During negative half cycle**

Diode: D_1 ——————▶ reverse biased

Diode: D_2 ——————▶ forward biased

Output signal ——————▶ obtained due to D_2 only

✓ Since both the halves of input a.c. (wave) are rectified, so the junction diode is called a full wave rectifier.

✓ $I_{ac} < I_{dc}$

✓ **Advantage:** In full wave rectifier, output is continuous, so its efficiency is more than that of the half wave rectifier.

However, the output is again fluctuating (or pulsating d.c.) which can be smoothened by using a filter circuit.

✓ **Expression for output d.c. voltage:**

$$Output\ d.c.\ voltage = Mean\ load\ current \times load\ resistance\ i.e.\ V_{dc} = I_{dc} \times R_{Load}$$

$$But\ I_{dc} = \frac{2I_o}{\pi}\ where\ I_o\ is\ the\ maximum\ value\ of\ the\ secondary\ full\ wave\ current$$

$$V_{dc} = \frac{I_o}{\pi} \times R_{Load}$$

$$E_{ac} = \frac{2V_o}{\pi}$$

Thus, output d.c. voltage in case of full wave rectifier is twice the output d.c. voltage in case of half wave rectifier.

Transistor

⇒ A transistor is an electronic device formed by p and n-type of semiconductor which is used in placed of a triode valve.

⇒ It was discovered in 1948 by American scientists Bardeen, Shockley and Brattain.
⇒ Transistor is a current operated device.
⇒ The word Transistor is a combination of two words (Transfer + Resistor = Transistor)
⇒ So, it is a transfer resistor.
⇒ Transistor does not need any heater or hot filament, transistor is small in size and light in weight.
⇒ Transistor consists of three main parts;

Emitter	Base	Collector
Provides majority charge carriers by which current flows in the transistor. Heavily doped.	Lightly doped and thin.	The size of collector region is larger than the two other regions. Moderately doped

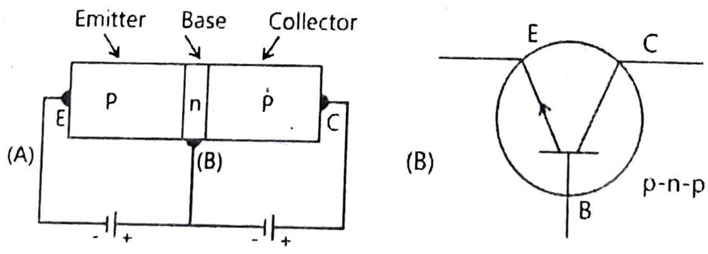
⇒ Transistors are of two type: p-n-p transistor and n-p-n transistor.
⇒ There are four possible ways of biasing the two P-N junctions (emitter junction and collector junction) of transistor.
⇒ Transistor is mostly used in these four modes/Regions.

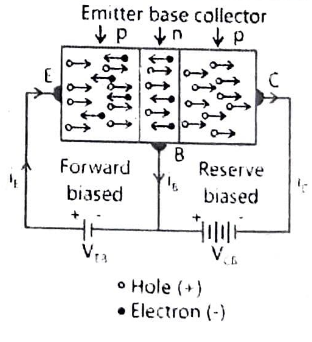
Active mode: Also known as linear mode operation.	**Saturation mode:** Maximum collector current flows and transistor acts as a closed switch from collector to emitter terminals.	**Cut-off mode:** Denotes operation like an open switch where only leakage current flows.	**Inverse mode:** The emitter and collector are inter changed.

Operating mode	Emitter base bias	Collector base bias
Active	Forward	Reverse
Saturation	forward	Forward
Cut off	Reverse	Reverse
Inverse	Reverse	Forward

⇒ Active region is the region in which transistor is mostly used.
⇒ By changing current in emitter portion, we can change the current in collector portion of transistor.
⇒ In each state of the transistor there is an input port and an output port. In general, each electrical quantity (V or I) obtained at the output is controlled by the input.
⇒ Transistor can be of the following two types;

P-N-P Transistor





⇒ It consists of a very thin layer of n-type semiconductor sandwiched between two small p-type semi-conductor.
⇒ The central slice is called the 'base' while the left and right crystals are called the 'emitter' and the 'collector' respectively.
⇒ The emitter is given a positive potential while the collector is given a negative potential with respect to the base.
⇒ Thus, the emitter-base (p-n) junction on the left is under forward-bias (high resistance). While the base-collector (n-p) junction on the right is reverse-bias.
⇒ The emitter-base (p-n) junction on the left is given a small forward bias (fraction of a volt) while the base-collector (n-p) junction is given a large reverse-bias (a few volts).

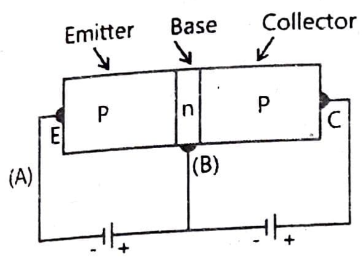
- ⇒ The symbol for this transistor is shown in Figure in which the direction of the arrow indicates the direction of current (direction of flow of holes).
- ⇒ Holes are the charge-carriers with in the p-n-p transistor, while electrons are the charge-carriers in the external circuit.
- ⇒ The small current which leaves the base terminal B is called the 'I_B' 'base-current' the larger current which leaves the collector terminal is called the 'collector-current' I_C. Both these currents combine to enter the emitter terminal E and constitute the emitter-current

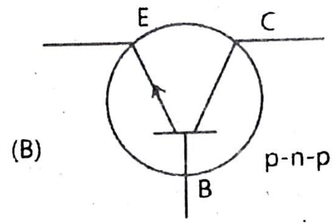
$$I_{Emitter} = I_{Base} + I_{Collector}$$

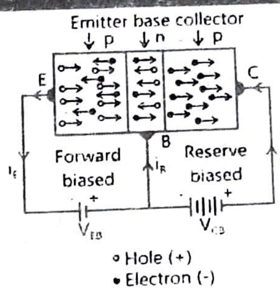
- ⇒ The base being very thin, the number of hole-electron combinations in it is very small, and almost all the holes entering the base from the emitter reach the collector. Hence;

$$I_{Emitter} \gg I_{collector}$$

N-P-N Transistor







- ⇒ It consists of a very thin slice of p-type semiconductor.
- ⇒ In this transistor the emitter is given a negative potential while the collector is given a positive potential with respective to the base.
- ⇒ So, the emitter-base (n-p) junction on the left is under forward-bias, while the base collector (p-n) junction on the right is denser reverse-bias.
- ⇒ The electrons are charge-carriers with in the n-p-n transistor as well as in the external circuit (whereas holes are the charge- carriers with in p-n-p transistor).
- ⇒ The small current entering the base terminal B is the base current I_B, while the larger current entering that collector terminal C is the collector-current I_C. Both currents combine to leave the emitter terminal E and constitute the emitter current I_E Thus,

$$I_E = I_B + I_C. \text{This equation show "Law of conservation of charges"}$$

- ⇒ $I_{emitter} > I_{colllector}$

Conceptual

Why Transistor is called "Transistor (Transfer + Resistor)" the logic behind this??

$$I_E = I_B + I_C;\ I_B << I_C, \text{and } I_B << I_E$$

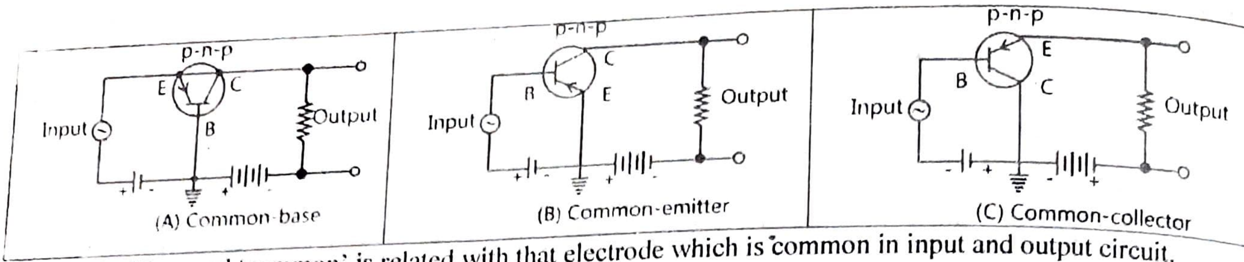
Thus, I_C is always less than I_E, but the difference is small.
Since the emitter junction is forward biased its resistance is small, while the collector junction is reverse biased, therefore its resistance is large. Thus, a transistor is a device which transfers I_E current from low resistance circuit to a high resistance circuit $I_C < I_E$. Thus, it is,

$$Transfer + resistor = transistor$$

(The name transistor originated from the action of the transistor).

A transistor can be connector in a circuit in three different ways. They are:

(i) Common- base configuration	(ii) Common-emitter configuration	(iii) Common-collector configuration



- ✓ The word 'common' is related with that electrode which is common in input and output circuit.
- ✓ This common electrode is generally grounded.
- ✓ Hence the above three configurations of connection are also called respectively as grounded- base configuration, grounded-emitter configuration, and ground-collector of connection are also called configuration. Each configuration has its own characteristics.

Characteristics of Transistor configuration

1) Common- base configuration:

Transistor as Common-Base Amplifier (n-p-n):

- ✓ As shown in figure, the base is made common to the input and output circuits.
- ✓ The emitter-base circuit is forward biased by a low-voltage battery V_{EB} so that the resistance of the input circuit is small.
- ✓ The collector-base output circuit is reverse-biased by means of a high-voltage battery V_{CC} so the resistance at the output circuit is quite large.
- ✓ R_L is a load resistor connected in the collector-base circuit...
- ✓ The weak input ac voltage signal is applied across the emitter-base circuit and the amplified output signal is obtained across the collector-base circuit.
- ✓ Let I_E, I_B *and* I_c be the emitter-current, base-current and collector-current irrespective when no ac voltage signal is applied to the input circuit. (The arrows represent the direction of hole current that is conventional current which is opposite to the direction of electron current). By Kirchhoff's first law, we have

$$I_E = I_B + I_C \qquad (i)$$

- ✓ Due to the collector-current I_C, the voltage drops across R_L is $I_C R_L$. Therefore, the collector-to-base voltage (potential difference between collector and base) V_{CB} would be given by;

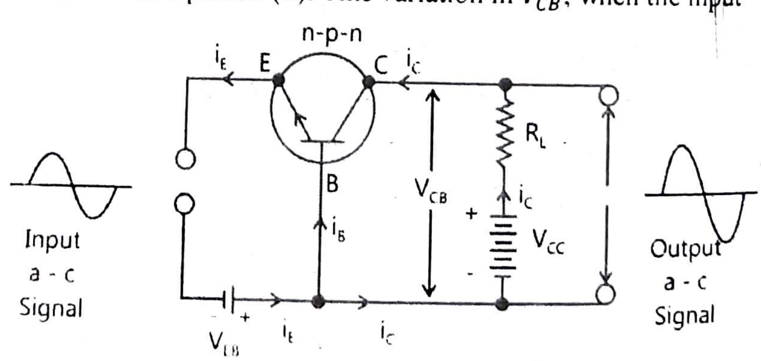
$$V_{CB} = V_{CC} - I_C R_L \qquad (ii)$$

- ✓ **How it amplifies:**

  When the input ac voltage signal is applied across the emitter-base circuit, it changes the emitter-base voltage and hence the emitter-current I_E which, in turn, changes the collector current I_C .consequently the collector to base voltage V_{CB} varies in accordance with equation (ii). This variation in V_{CB}, when the input signal is applied, appears as an amplified output.

- ✓ ***Phase relationship between input and output voltage signal in CB circuit:***

  The output voltage signal is in with the input voltage signal in the common-base amplifier



2) Common- Emitter configuration:

Common Emitter Amplifier Using a p-n-p Transistor

✓ Figure shows the common-emitter amplifier circuit using an n-p-n transistor. The emitter is made common to the input and output circuits.

✓ The input (base-emitter) circuit is forward-biased by a low-voltage battery V_{BE} so that the resistance of the input circuit is small. The output (collector-emitter) circuit is reverse-biased by means of a high voltage battery V_{CC} so that the resistance at the output circuit is high.

R_L is a load resistance connected in the collected-emitter output circuit...

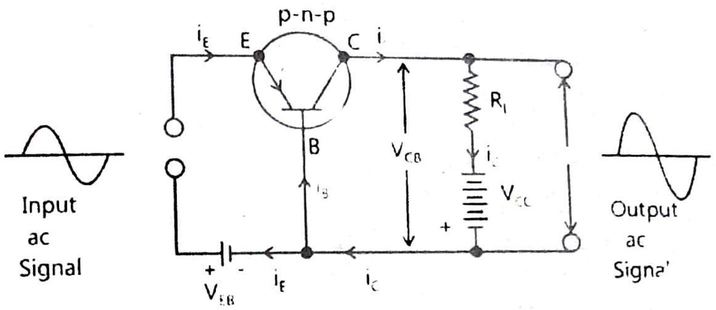
✓ The weak input ac signal is applied across the base-emitter circuit and the amplified output signal is across the collector-emitter circuit.

✓ Let I_E, I_B and I_c be the emitter-current, base-current and collector-current irrespective when no ac voltage signal is applied to the input circuit. (The arrows represent the direction of hole current, that is conventional current which is opposite to the direction of electron current). By Kirchhoff's first law, we have

$$I_E = I_B + I_C \qquad (i)$$

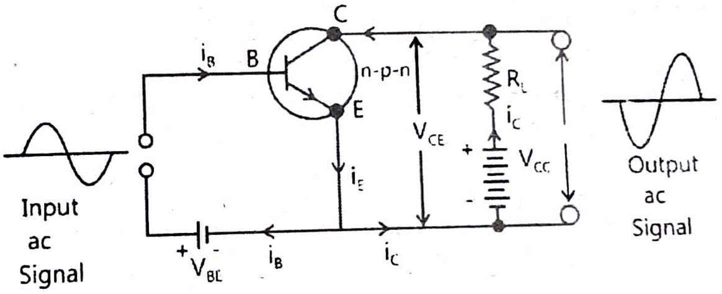
✓ Due to the collector-current I_c, (which is only slightly smaller that I_E), the voltage drop across R_L is $I_C R_L$. Therefore, the collector-to-base voltage (potential difference between collector and base) VCB would be given by

$$V_{CE} = V_{CC} - I_c R \qquad (ii)$$



✓ ***How it amplifies?***

When the input ac voltage signal is applied across the emitter-base circuit, it changes the emitter-base voltage and hence the emitter-current I_E which, in turn, changes the collector current I_C .consequently the collector to base voltage V_{CE} varies in accordance with equation (ii). This variation in V_{CE}, when the input signal is applied, appears as an amplified output.



✓ ***Phase Relationship between input and output voltage signals:*** In a common-emitter amplifier the input voltage signal and the output voltage signal obtained across the collector and the emitter are out of phase with each other.

✓ The output voltage signal is 180° out of phase with the input voltage signal in the common-emitter amplifier.

Gain in Transistors Combinations

Gains in Common-Base Configuration

1) **AC current gain:**

It is defined as the ratio of the change in the collector- current to the change in the emitter current at a constant collector-to-voltage,

➔ and is denoted by α. Thus;

$$\alpha_{ac} = \left(\frac{\Delta I_c}{\Delta I_E}\right)_{VCB}$$

➔ The value of $\alpha$is slightly less than 1 (actually there is a little current loss).

2) **AC Voltage Gain:**

It is defined as the ratio of the changes in the output voltage to the change in the input voltage,

➔ and is denoted by A_v

➔ Suppose, on applying ac input voltage signal, the emitter current changes by ΔI_C and correspondingly the collector-

Gains in Common-Emitter Configuration

1) **AC current Gains:**

It is defined as the ratio of the collector current to the current,

➔ and is denoted by β_{dc}.

$$\beta_{dc} = \frac{I_C}{I_B}$$

In a typical transistor, a small base-current ($\approx$ µ 10 A) produces large collector-current ($\approx$ µ 500 A).

$$Thus\ \beta_{dc} = \frac{500}{10} = 50$$

2) **AC current Gain:** It is defined as the ratio of the base- the collector-current to the change in the base-current at a constant collector to emitter voltage,

➔ and is denoted by β_{ac} .

current changes by ΔI_C . If R_{in} and R_{out} the resistances of the input and the output circuits respectively, then:

$$A_v = \frac{\Delta I_c \times R_{output}}{\Delta I_E \times R_{imput}} = \frac{\Delta I_c}{\Delta I_E} \times \frac{R_{output}}{R_{imput}}$$

➔ $\frac{\Delta I_c}{\Delta I_E}$ is called Ac Current gain

➔ $\frac{R_{output}}{R_{imput}}$ is called Resistance gain.

$\therefore A_v = \alpha \times Resistance\ gain$

➔ Since the resistance gain is quite high, A_V is also quite high although a is slightly less than 1.

3) AC Power Gain:

It is defined as the ratio of the change in the output power to the change in the input power.

Since $power = current \times voltage$, we have

$ac\ power\ gain = ac\ current\ gain \times ac\ voltage - gain = \alpha^2 \times resistance\ gain$

$$\beta_{AC} = \left(\frac{\Delta I_c}{\Delta I_B}\right)_{V_{CE}}$$

3) Voltage gain: Suppose, on applying ac input voltage signal, the base-current changes by ΔI_B and correspondingly the output collector-current change by ΔI_c . If R_{in} and R_{out} be the resistance of the input and the output circuits respectively.

$$A_v = \frac{\Delta I_c \times R_{output}}{\Delta I_B \times R_{imput}} = \frac{\Delta I_c}{\Delta I_B} \times \frac{R_{output}}{R_{imput}}.$$

➔ $\frac{\Delta I_c}{\Delta I_B}$ is called Ac current gain

➔ $\frac{R_{output}}{R_{imput}}$ is called Resistance gain.

$\therefore A_v = \beta_{AC} \times Resistance\ gain$

Since $\beta_{ac} >> \alpha_{ac}$, the ac voltage gains in common-emitter amplifer is larger compared to the common base amplifier., although the resistance gain is smaller.

4) AC power gain:

It is defined as the ratio of the change in the output power to the change in the input power.

■ the ac power gain in common-emitter amplifier is extremely large compared to that in common-base amplifier

Relation Between α and β

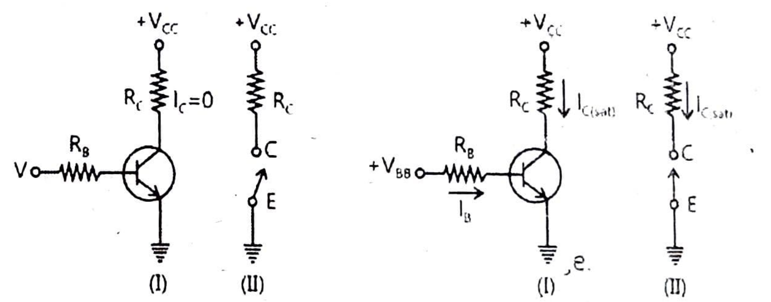
CB current gain (α): CB current gain (a) is the ratio of output current to the input current in common base configuration of a transistor.

$$\alpha_{dc} = \frac{I_c}{I_E} \text{ and } \alpha_{AC} = \frac{\Delta I_c}{\Delta I_E}$$

CE current gain (β): CE current gain (b) is the ratio of the output current to the input current in emitter configuration of the transistor.

$$\beta_{DC} = \frac{I_c}{I_B} \text{ and } \beta_{AC} = \frac{\Delta I_c}{\Delta I_B}$$

The CB current gain a and CE current gain b are related by the following relations;



Open switch
(a)

Closed switch
(b)

$$\frac{1}{\alpha} = 1 + \frac{1}{\beta}; \alpha = \frac{\beta}{\beta + 1}; \beta = \frac{\alpha}{1 - \alpha}$$

The above relations are applicable for both dc and ac current gains.

> The value or a is always less than 1. $\alpha \sim 0.9$ to 0.99 or more. The value of b is always much greater than 1. $\beta \sim 95$ to 99 or so.

Transistor as a switch

⇒ We have already studied about forward and reverse biasing and their characteristics.

⇒ When the diode is forward biased, it conducts current easily and behaves like a closed switch.

⇒ However, when diode is reverse biased, it practically conducts no current and behaves like an open switch.

⇒ A transistor can also be used as a switch by making emitter-base junction either reverse biased or sufficiently forward biased.

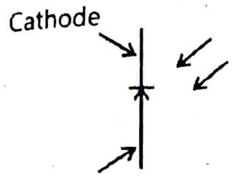
Transistor as open switch. In Figure (a), the base-emitter junction is not forward biased. Therefore, base current $I_B = 0$. As a result, collector current $I_c (= \beta I_B)$ is also zero. Under this condition, the transistor behaves as an open switch. In other words, there is an open between the collector and emitter as indicated in figure.

Transistor as closed switch. In Figure (b), the base-emitter junction is sufficiently forward biased so that base current I_B is made large enough to cause maximum collector current to flow. This maximum value of collector current is called saturation current $I_C(sat)$. Under this collector and emitter as shown in Fig.

Optoelectronic junction device

- ✓ Those devices made up of semi-conductor which make use of photon are called optoelectronic device.
- ✓ Here we will discuss three types;
  1) Photodiode
  2) Light emitting diode
  3) Photovoltaic or solar cell

Photo Diode



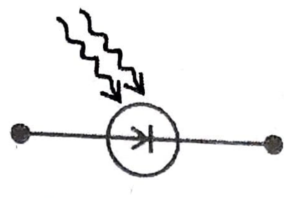
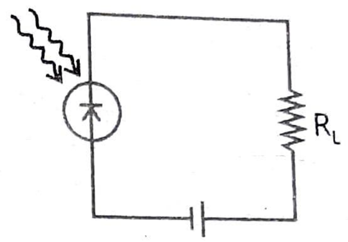


Photo diode



⇒ A reverse biased special p-n junction diode having transparent window is known as photo diode and when it is illuminated with light, the reverse diode current varies linearly with the light flux.

⇒ **Construction:** reverse biased p-n junction diode is enclosed in a clear plastic envelope. Light is allowed to fall on the surface of the plastic facing the diode. The output voltage is taken across the load resistance R_L.

⇒ **Principle.** When a rectifier diode is reverse biased, it has a very small reverse leaked current. The same is true for a photo-diode. The reverse current is produced by thermally generated electron-hole pairs which are swept across the junction by the electric field create by the reverse voltage.

⇒ when its PN junction is exposed to light, the reverse current increases with the increase in light intensity and vice-versa. $Reverse\ current \propto Light\ intensity$

⇒ as the incident light intensity increases, the resistance of the device (photo-diode) decreases.

Conceptual:

(a) When no light is incident on the PN junction of photo-diode, the reverse current I_r is extremely small. This is called dark current. The resistance of photo-diode with no incident light is called dark resistance (R_R)

$$Dark\ Resistance, R_R \propto \frac{V_R}{Dark\ current}$$

(b) When light is incident on the junction of the photo-diode, there is a transfer of energy from the incident light (photons) to the atoms in the junction. This will create more free electrons (and more holes). These additional free electrons will increase the reverse current.

(c) As the intensity of light increases, the reverse current IR goes on increasing till it becomes maximum. This is called saturation current.

⇒ Photo-diodes are operated in reverse photo-diode is used to detect photo radiation.

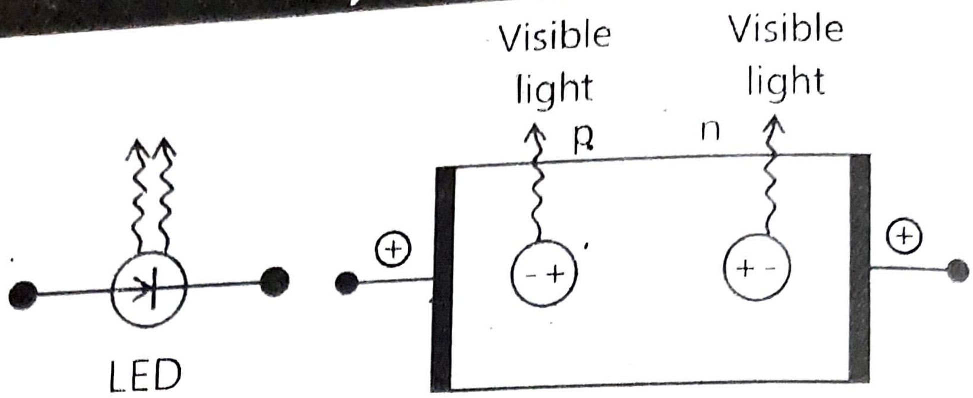
⇒ Light variations affect minority carrier based reverse current much more than the forward current

⇒ **Uses;**

1) Photo diodes are used as photo detectors intensity of radiation.
2) used as light operated switches.

3) used in fast reading of film sound tracks and tapes

Light Emitting Diode



⇒ A special heavily doped P-N junction diode which emits spontaneous radiation when forward biased is known as light emitting diode (LED).

⇒ LEDs made of elemental semiconductor like germanium (Ge) and silicon (Si) emit energy in the form of infra-red (or heat) radiation.

⇒ Theory: When a p-n junction diode is forward biased (See Fig. 26.39), the electrons injected to p-side of the junction diode falls from the conduction band to the valence band and recombine with the holes in the valence band. [This is equivalent to the jumping of electrons from higher energy state (i.e., conduction band) to lower energy state (i.e., valence band)].

Hence, energy is known as electro-luminescence. The energy of the photon of visible light by $h_\nu = E_g$, where E_g is the energy gap between conduction band and valence band v is the frequency of emitted visible radiation. The wavelength of the emitted light is given by

$$\frac{hc}{\lambda} = E_g \quad or \; \lambda \frac{hc}{E_g}$$

⇒ Uses:

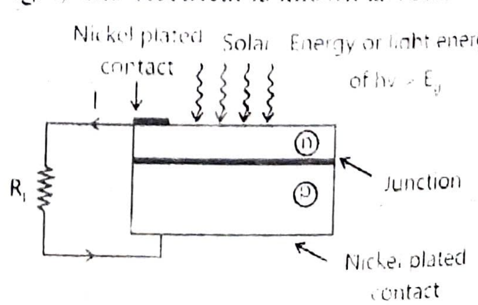
1) Used in digital displays in watches and calculators.
2) Used as indicator lamps.
3) Used as decorating lights.
4) Used as light lamp and in torches.
5) Light emitting diodes which emit infra-red light are used in burglar alarm.
6) Used in remote control schemes.

⇒ Advantages associated:

1) Low cost
2) Easily manufactured.
3) Can be switched on and off very fast.
4) Can emit monochromatic light as well as white light.
5) Longer life than the incandescent bulb.
6) LED works at low voltage as compared to the incandescent bulb.

Solar cell or Photo Voltaic Device

⇒ A special p-n junction diode which converts solar energy (sun light) into electrical is known as solar cell or photovoltaic device. Junction surface of these diodes is kept large so that large radiations are caught.



⇒ A simple solar cell consists of a p-n junction of which n-region is very thin and p-region is thick.

⇒ Discussion:

♥ When solar energy or light energy falls on the cells, electron-hole pairs are generated in both n-region and p-region of the junction in diode.

- The electrons from p-region diffuse through the junction to n-region and holes from n-region diffuse through the junction to the p-region due to electric field of depletion layer.
- If p-n junction diode is open circuited, then holes and electrons will collect or accumulate on the two sides of the junction. This gives rise to an open circuit.

Uses:

1) In street lights.
2) In solar heaters.
3) In power supply of satellites and space vehicles.
4) In calculators.

Some important points and tricks

1) A semiconductor is a perfect insulator at 0 °K.
2) At higher temperature, the conductivity of the semiconductor increases because of the increase in the number density of the charge carriers.
3) A pure semiconductor has negative temperature coefficient.
4) A slight trace of doping changes the conductivity of intrinsic semiconductor to a large extent.
5) In extrinsic semiconductors,
for n-type material, $n_e > n_h$
for p-type material\$n_e < n_h$
6) Depletion region in junction diode contains charges which are fixed donor and acceptor ions.
7) When semiconductor is unbiased, drift current and diffusion currents are equal in magnitude and opposite in direction.
8) The semiconductor devices are temperature sensitive devices.
9) The mobility of electrons as well as of holes in a semiconductor decreases with increase in temperature but it is independent of the number of electrons or holes.
10) The symbolic representation of p-n junction diode indicates the direction of conventional current flow. It is directed from p to n when forward biased i.e., according to the arrow head Representing p-section.
11) Potential barrier at p-n junction opposes forward current but aids reverse current.
12) In ideal junction diode acts as an open circuit.
13) A p-n junction diode can be considered to be equivalent to a capacitor with p and n regions acting as the plates of the capacitors and depletion layer as the dielectric medium.
14) In unbiased p-n junction, the junction current at equilibrium is zero because in this condition, there is no charge which can cross the junction.
15) During the forward bias of p-n junction diode, the depletion region becomes thin and the junction diode offers a low resistance to the motion of charge carrier.
16) The maximum reverse voltage the diode must withstand is called peak inverse voltage (PIV).
17) In p-n junction diode, holes travel from p region to n region because there is a greater concentration of holes in p region as compared to n region.
18) In p-n junction diodes, forward current is measured in mA while reverse current is measured in μA.
19) The current due to minority charge carriers in the junction diode is independent of the applied voltage. It only depends upon the temperature of the diode.
20) In p-n junction diode, there is full conduction (r = 0) when forward biased and no conduction (r = ∞) when reverse biased.
21) In ideal junction diode when forward biased offers zero resistance. Voltage drop across such a junction diode is zero. A reverse biased diode offers infinite resistance and voltage drop across it is equal to voltage applied.
22) Efficiency of half-wave rectifier is less than 50% while that of the full-wave rectifier is less than 81%.
23) Zener diodes are specially designed diodes operated in reverse breakdown voltage region.
24) As zener diode provides a large current change for small voltage change, it is used as voltage regulator.
25) The p-n junction di.de which emits light in forward bias condition is called LED.
26) In photodiode, for the emission of electron from cathode, there must be $hv > E_g$.
27) The solar cell is a device which converts solar energy into electrical energy.
28) The word transistor refers to transfer of resist. nce.
29) The mobility of electron is two to three times the mobility of holes. Therefore n-p-n devices are fast and hence preferred.
30) Cross-sectional area of base is very large as compared to that of emitter. Cross-sectional area of collector is less than base but greater than that of emitter.
31) When npn or pnp transistor are used as common emitter amplifier the output and input signals are 180°out of phase.
32) Irrespective of configuration the emitter of a transistor is always in forward bias and collector is in reverse bias.

33) The d.c. current gain is always less than 1.
34) Transistor can be used as an amplifier and oscillator but not as a rectifier.
35) Common-emitter transistor amplifier is preferred over common-base transistor amplifier due to large current gain.
36) The fermi energy of a given material is the energy of a quantum state that has the probability 0.5 of being occupied by an electron.
37) In a common-base transistor amplifier:
    i. the input and output signals are in the same phase.
    ii. there is no amplification of current of a given signal.
    iii. there is an amplification of voltage and power of the given signal.
38) In a common-emitter transistor amplifier:
    i. the input and output signals are out of phase by π or 180°.
    ii. there is amplification of the current, voltage and power of the given signal.
39) The forbidden energy gap for pure germanium is 0.72 eV and for silicon is 1.1 eV.
40) In a doped semiconductor, the density of electrons and holes is not equal. It can be shown that $n_e n_h = n_i^2$.
41) The electric field set-up across the potential barrier is of the order of 7×10^5 V/m for silicon diode and 3×10^5 V/m for germanium diode.